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NUCLEAR CRITICALITY SAFETY:

3-DAY TRAINING COURSE

Offered at

The Los Alamos National Laboratory

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PART II

THREE EARLY CRITICAL EXPERIMENT ACCIDENTS

Los Alamos, New Mexico — June 6, 1945[16]

(Pseudosphere of uranium cubes, water reflected, local control)

The experiment was designed before the days of remote control and was intended to establish the critical mass of enriched uranium metal when it was surrounded by hydrogenous material. The uranium mass of 35.4 kilograms (average enrichment 79.2%) was stacked in the form of a pseudosphere constructed of 0.5-inch cubes and blocks 0.5 x 0.5 x 1 inch. The core was in a 6-inch cubical polyethylene box, with the void space filled with polyethylene blocks. The whole assembly was placed in a large tank that was then partially filled with water.

The assembly became critical (unexpectedly) before water had completely covered the polyethylene box. The situation was aggravated because no scram device was built into the system and the inlet and drain valves were 15-feet apart. Before the system was reduced to a safe subcritical state 5 or 10 seconds later, a total of 3 to 4 x 10^{16} fissions were created, an energy release sufficient to raise the average temperature of the metal to more than 200 degrees Celsius. Subsequent examination of the polyethylene box showed that it was not watertight. It is probable that water seeped slowly into the uranium assembly as the level was being raised above the bottom of the box. The additional moderation then caused the supercritical situation which was terminated by boiling of the water within the box and next to the metal cubes.

Calculations by O. D. Thompson, formerly of the LANL Criticality Safety Staff have provided some insight into this accident. Nesting spherical shells of U(79.2), having a thickness of 8 mm and a total mass of 35.4 kg, were evaluated with gaps between the shells of 0.5- and 1-mm. Adding water to the gaps increased the multiplication factor (k) by 0.04 for the 1-mm gap, while for the 0.5-mm case this increase was found to be 0.02. These results apply to the assembly fully reflected by water, where the calculated multiplication factor was 1.024 and 1.018, respectively. The full-water reflector was found to be worth 0.21 in k. While the geometry of the calculations represents only a rough approximation of the actual assembly, refinements are probably not justified. Indications are that the uranium cubes were "as cast," so the actual volume available to the water cannot be known.

The characteristics of excursions of large masses of fissile metal in water are, at best, poorly known. A calculation by G. E. Hansen has shown that for a 0.86-cm-radius ^{235}U sphere in water, 15% of the fissions occur in the outer 0.05 cm, and the fission density in this region is six times than at the center. A spike of 3 x 10^{15} fissions would then raise the temperature 130°C while the central regions would remain relatively cool with a temperature rise of only 19°C. The initial spike must have been of this order of magnitude, with the majority of the fissions following at a much lower average power.

Los Alamos, New Mexico — August 21, 1945[16,21]

(Plutonium core reflected with tungsten carbide, hand assembly)

Los Alamos, New Mexico — May 21, 1946[16,21]

(Plutonium core reflected with beryllium, hand assembly)

These two accidental excursions occurred with the same core and were, in several respects, quite similar. The core consisted of two hemispheres of delta-phase plutonium coated with 5 mils (0.005 inches) of nickel. The total core mass was 6.2-kg, and the density was about 15.7 g/cc.

In the first accident, a critical assembly was being created by hand stacking 4.4-kg tungsten carbide bricks around the plutonium core. Figure 8 shows a re-enactment of the configuration with about half the tungsten blocks in place. The lone experimenter had almost completed the stack and was moving the final block over the assembly for a total reflector mass of 236 kg when he noticed from the nearby neutron counters that the addition of this brick would make the assembly supercritical. As he withdrew his hand, the brick slipped and fell onto the center of the assembly, adding sufficient reflection to make the system super-prompt critical, and a power excursion occurred. He quickly pushed off the final brick and proceeded to unstack the assembly. His exposure was estimated at 510 rem from a yield of 10^{16} fissions.

An Army guard assigned to the building, but not helping with the experiment, was irradiated in the amount of approximately 50 rem. The nickel cladding on the plutonium core did not rupture.

In the second accident, the techniques involved in creating a metal critical assembly were being demonstrated to several people. The system consisted of the same plutonium core, reflected in this case by beryllium. The top and final hemispherical beryllium shell was being lowered slowly into place; one edge was touching the lower beryllium hemisphere, while the opposite edge was resting on the tip of a screwdriver (Fig. 9). The person conducting the demonstration was holding the top shell with his left thumb placed in an opening at the polar point, while slowly working the screwdriver out with his right hand. At this time the screwdriver slipped from under the shell and the shell seated on the lower hemisphere. An excursion occurred at once, the shell was thrown to the floor, and all personnel left the room. The yield of this excursion was 3×10^{15} fissions, and again there was no rupture of the nickel cladding. The eight people in the room were irradiated in the amounts of 2100, 360, 250, 160, 110, 65, 47 and 37 rem. The man who performed the experiment died 9 days later as a result of radiation injury.

The results of calculation of the fission rate in this sphere as a function of time for several values of excess reactivity are shown in Fig. 10. Fig. 11 represents the total number of fissions to be expected as a function of time for these same excess reactivities. These calculations were performed by T. P. McLaughlin of the Los Alamos National Laboratory.

These data are applicable to both accidents because the difference in reflector material had only a small effect on the neutron kinetics. In the first experiment, if the excess reactivity did not exceed 0.15$, the assembly must have been together for several seconds, which is not unreasonable. In the second event, the experimenter was better prepared to disassemble the material, and it is thought that this was done in a fraction of a second, and perhaps less than 0.5 second.

The known parameters would then be satisfied by an excess reactivity of about 0.10$.

The second of these plutonium sphere accidents convinced people that hand-stacking fissionable material in critical or near-critical configurations entailed unacceptable risks. A remote critical assembly facility was built at the same Los Alamos site (TA-18, called Pajarito Site) where this accident occurred and is still in use. To date, Pajarito Site has conducted many thousands of approaches to criticality with no injuries caused by nuclear excursions, and only minor equipment damage from the approximately ten excursions that have occurred. In fact, this site has amassed a record of about 40 years without a lost-time accident.

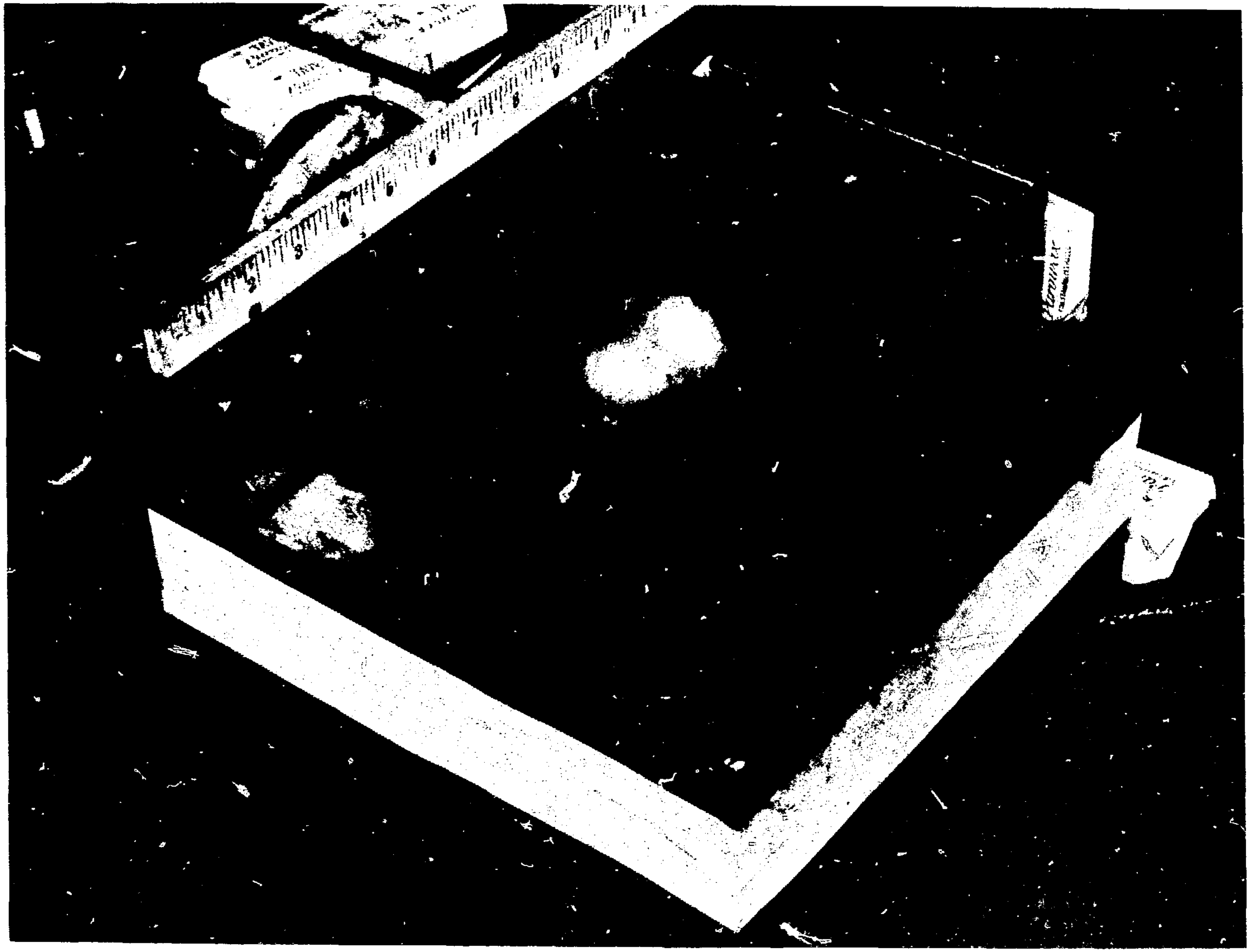

Figure 8. Plutonium sphere partially reflected by tungsten carbide blocks.

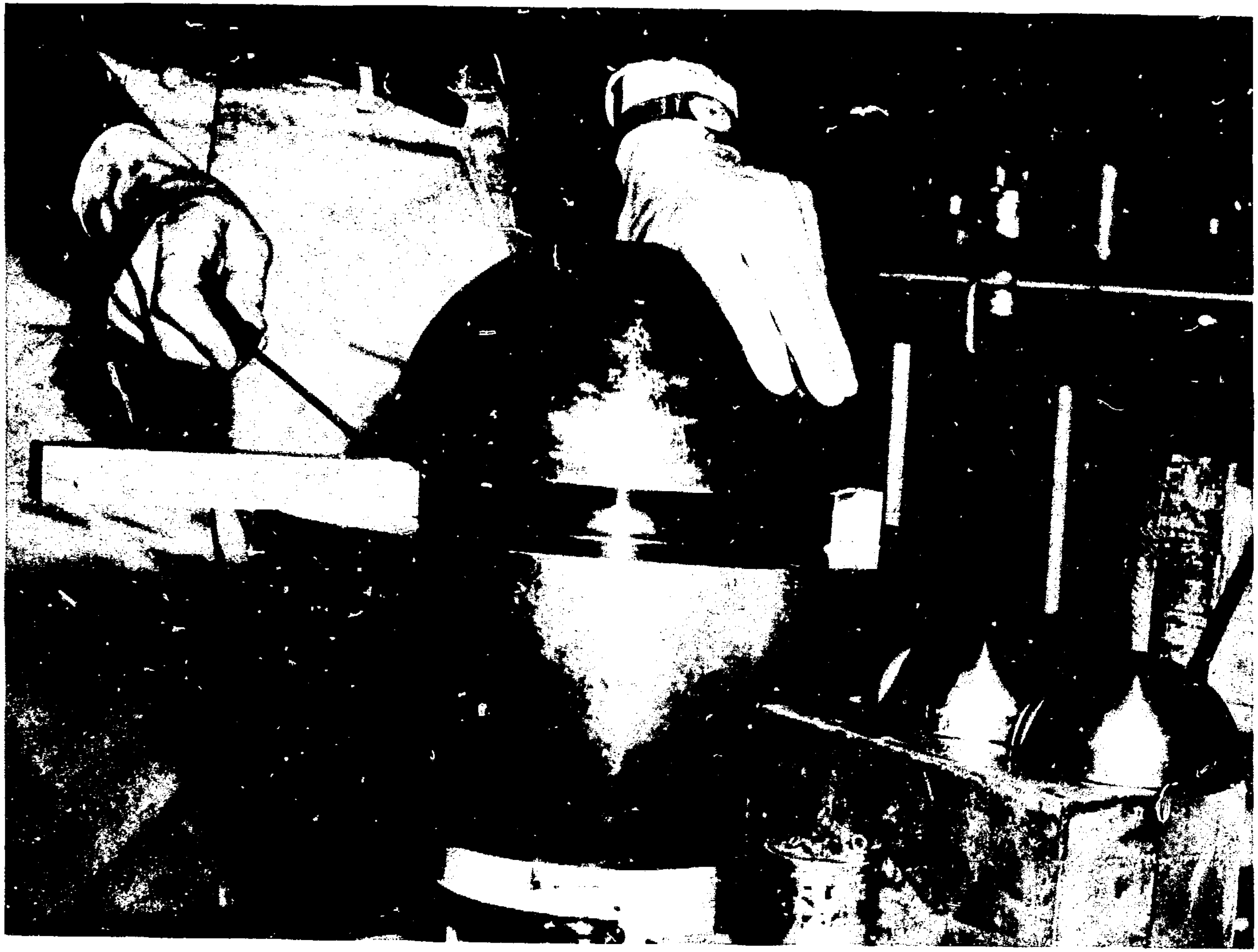

Figure 9. Configuration of beryllium reflector shells prior to the accident of May 21, 1946.

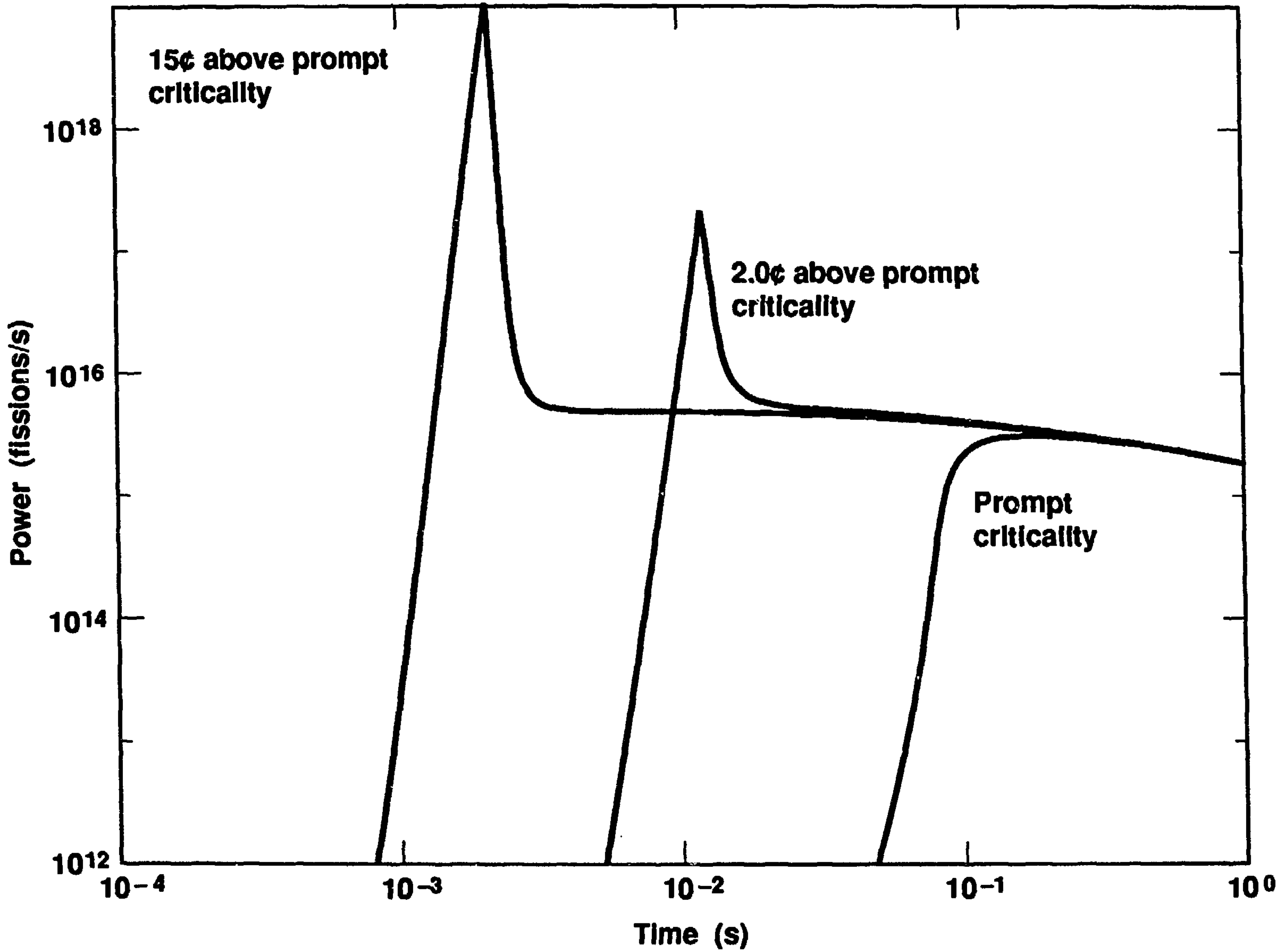

Figure 10. Calculated fission rate for the 6.2-kilogram plutonium sphere.

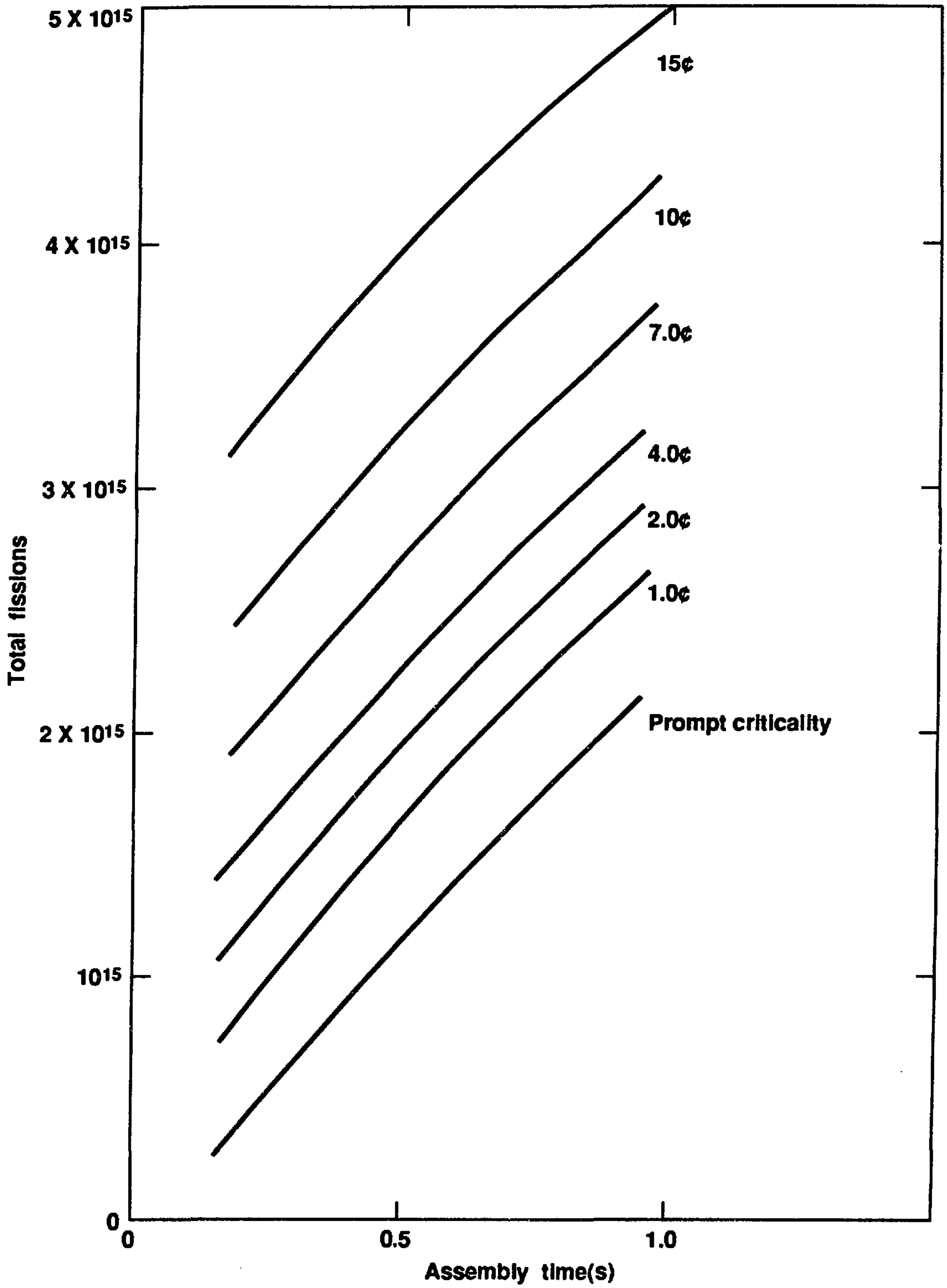

Figure 11. Calculated total fissions vs. time for the 6.2-kilogram plutonium sphere.

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